CELL SELECTION WITH STTD AND SSDT

CLAIM TO PRIORITY OF PROVISIONAL APPLICATION

This application claims priority under 35 U.S.C. § 119(e)(1) of provisional application serial number 60/121,789, filed 02/26/99.

FIELD OF THE INVENTION

This invention relates to wideband code division multiple access (WCDMA) for a communication system and more particularly to site selection diversity (SSDT) power control with space-time transmit diversity for WCDMA signals.

BACKGROUND OF THE INVENTION

Present code division multiple access (CDMA) systems are characterized by simultaneous transmission of different data signals over a common channel by assigning each signal a unique code. This unique code is matched with a code of a selected receiver to determine the proper recipient of a data signal. These different data signals arrive at the receiver via multiple paths due to ground clutter and unpredictable signal reflection. Additive effects of these multiple data signals at the receiver may result in significant fading or variation in received signal strength. In general, this fading due to multiple data paths may be diminished by spreading the transmitted energy over a wide bandwidth. This wide bandwidth results in greatly reduced fading compared to narrow band transmission modes such as frequency division multiple access (FDMA) or time division multiple access (TDMA).

New standards are continually emerging for next generation wideband code division multiple access (WCDMA) communication systems as described in Provisional U.S. Patent Application No. 60/082,671, filed April 22, 1998, and incorporated herein by reference. These

WCDMA systems are coherent communications systems with pilot symbol assisted channel estimation schemes. These pilot symbols are transmitted as quadrature phase shift keyed (QPSK) known data in predetermined time frames to any receivers within range. The frames may propagate in a discontinuous transmission (DTX) mode. For voice traffic, transmission of user data occurs when the user speaks, but no data symbol transmission occurs when the user is silent. Similarly for packet data, the user data may be transmitted only when packets are ready to be sent. The frames are subdivided into fifteen equal time slots of 0.67 milliseconds each. Each time slot is further subdivided into equal symbol times. At a data rate of 30 KSPS, for example, each time slot includes twenty symbol times. Each frame includes pilot symbols as well as other control symbols such as transmit power control (TPC) symbols and rate information (RI) symbols. These control symbols include multiple bits otherwise known as chips to distinguish them from data bits. The chip transmission time (T_C), therefore, is equal to the symbol time rate (T) divided by the number of chips in the symbol (N).

Previous studies have shown that multiple transmit antennas may improve reception by increasing transmit diversity for narrow band communication systems. In their paper New Detection Schemes for Transmit Diversity with no Channel Estimation, Tarokh et al. describe such a transmit diversity scheme for a TDMA system. The same concept is described in A Simple Transmitter Diversity Technique for Wireless Communications by Alamouti. Tarokh et al. and Alamouti, however, fail to teach such a transmit diversity scheme for a WCDMA communication system.

Another improvement in communication systems includes site selection diversity transmit power control (SSDT). The SSDT will be explained with reference to the flow diagram of FIG. 7. A mobile receiver frequently receives signals from multiple base stations. The mobile receiver calculates a signal-to-interference (SIR) ratio for each respective base station. These SIR values are applied to a selection circuit 720 in the mobile receiver. The selection circuit determines the base station with the greatest SIR and sends the identity of this base station to the control network 630 on a frame-by-frame basis. The control network then transmits the next data frame only on the selected

base station. This reduces slow lognormal fading and interference within the communication system. SSDT further reduces interference at the mobile receiver and within the cell.

A problem arises with this simplified selection scheme when one or more of the base stations employ transmit diversity. This is because a good SIR may not correspond to a reduced bit error rate within the cell. An improved SIR due to STTD or other transmit diversity methods, therefore, may have a superior bit error rate compared to another base station having no diversity. Previous designs fail to offer or suggest a solution to SSDT base station selection when one or more base stations employ transmit diversity.

SUMMARY OF THE INVENTION

The foregoing problems are resolved by a method of operating a communication circuit comprising the steps of receiving a plurality of signals from a plurality of remote transmitters and determining which of the plurality of remote transmitters use transmit diversity. A signal strength of each respective signal of the plurality of signals is calculated. One of the remote transmitters is selected in response to the steps of determining and calculating.

The present invention reduces interference at the mobile receiver. Transmit power within the cell is reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention may be gained by reading the subsequent detailed description with reference to the drawings wherein:

FIG. 1 is a simplified block diagram of a typical transmitter using Space Time Transit Diversity (STTD) of the present invention;

FIG. 2 is a block diagram showing signal flow in an STTD encoder of the present invention that may be used with the transmitter of FIG. 1;

FIG. 3 is a schematic diagram of a phase correction circuit of the present invention that may be used with a receiver;

FIG. 4 is a block diagram of a receiver that with the phase correction circuit of FIG. 3;

FIG. 5 is a block diagram showing signal flow in a communication network;

FIG. 6 is a flow diagram showing base station selection of the present invention;

FIG. 7 is a flow diagram showing base station selection of the prior art;

FIG. 8 is a diagram showing simulation parameters for the simulation results of FIG. 9; and

FIG. 9 is a simulation comparing SSDT to STTD and SSDT.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, there is a simplified block diagram of a typical transmitter using Space Time Transit Diversity (STTD) of the present invention. The transmitter circuit receives pilot symbols, TPC symbols, RI symbols and data symbols on leads 100, 102, 104 and 106, respectively. Each of the symbols is encoded by a respective STTD encoder as will be explained in detail. Each STTD encoder produces two output signals that are applied to multiplex circuit 120. The multiplex circuit 120 produces each encoded symbol in a respective symbol time of a frame. Thus, a serial sequence of symbols in each frame is simultaneously applied to each respective multiplier circuit 124 and 126. A channel orthogonal code C_m is multiplied by each symbol to provide a unique signal for a designated receiver. The STTD encoded frames are then applied to antennas 128 and 130 for transmission.

Turning now to FIG. 2, there is a block diagram showing signal flow in an STTD encoder of the present invention that may be used with the transmitter of FIG. 1 for pilot symbol encoding. The pilot symbols are predetermined control signals that may be used for channel estimation and other functions as will be described in detail. Operation of the STTD encoder 112 will be explained with reference to TABLE I. The STTD encoder receives pilot symbol 11 at symbol time T, pilot symbol S_1 at symbol time $2T$, pilot symbol 11 at symbol time $3T$ and pilot symbol S_2 at symbol time $4T$ on lead 100 for each of sixteen time slots of a frame. For a first embodiment of the present

invention having a data rate of preferably 32 KSPS, the STTD encoder produces a sequence of four pilot symbols for each of two antennas corresponding to leads 204 and 206, respectively, for each of the sixteen time slots of TABLE I. The STTD encoder produces pilot symbols B_1, S_1, B_2 and S_2 at symbol times *T-4T*, respectively, for a first antenna at lead 204. The STTD encoder simultaneously produces pilot symbols B_1, $-S_2^*$, $-B_2$ and S_1^* at symbol times *T-4T*, respectively, at lead 206 for a second antenna. Each symbol includes two bits representing a real and imaginary component. An asterisk indicates a complex conjugate operation or sign change of the imaginary part of the symbol. Pilot symbol values for the first time slot for the first antenna at lead 204, therefore, are 11, 11, 11 and 11. Corresponding pilot symbols for the second antenna at lead 206 are 11, 01, 00 and 10.

The bit signals $r_j(i+\tau_j)$ of these symbols are transmitted serially along respective paths 208 and 210. Each bit signal of a respective symbol is subsequently received at a remote mobile antenna 212 after a transmit time τ corresponding to the j^{th} path. The signals propagate to a despreader input circuit (not shown) where they are summed over each respective symbol time to produce input signals R_j^1, R_j^2, R_j^3 and R_j^4 corresponding to the four pilot symbol time slots and the j^{th} of L multiple signal paths as previously described.

	ANTENNA 1				ANTENNA 2			
SLOT	B_1	S_1	B_2	S_2	B_1	$-S_2^*$	$-B_2$	S_1^*
1	11	11	11	11	11	01	00	10
2	11	11	11	01	11	11	00	10
3	11	01	11	01	11	11	00	00
4	11	10	11	01	11	11	00	11
5	11	10	11	11	11	01	00	11
6	11	10	11	11	11	01	00	11
7	11	01	11	00	11	10	00	00
8	11	10	11	01	11	11	00	11
9	11	11	11	00	11	10	00	10
10	11	01	11	01	11	11	00	00
11	11	11	11	10	11	00	00	10
12	11	01	11	01	11	11	00	00
13	11	00	11	01	11	11	00	01
14	11	10	11	00	11	10	00	11
15	11	01	11	00	11	10	00	00
16	11	00	11	00	11	10	00	01

TABLE I

The input signals corresponding to the pilot symbols for each time slot are given in equations [5-8]. Noise terms are omitted for simplicity. Received signal R_j^1 is produced by pilot symbols (B_1, B_1) having a constant value (11,11) at symbol time *T* for all time slots. Thus, the received signal is equal to the sum of respective Rayleigh fading parameters corresponding to the first and second antennas. Likewise, received signal R_j^3 is produced by pilot symbols $(B_2, -B_2)$ having a constant value (11,00) at symbol time *3T* for all time slots. Channel estimates for the Rayleigh fading parameters corresponding to the first and second antennas, therefore, are readily obtained from input signals R_j^1 and R_j^3 as in equations [9] and [10].

$$R_j^1 = \alpha_j^1 + \alpha_j^2 \qquad [5]$$

$$R_j^2 = \alpha_j^1 S_1 - \alpha_j^2 S_2^* \qquad [6]$$

$$R_j^3 = \alpha_j^1 - \alpha_j^2 \qquad [7]$$

$$R_j^4 = \alpha_j^1 S_1 + \alpha_j^2 S_1^* \qquad [8]$$

$$\alpha_j^1 = (R_j^1 + R_j^3)/2 \qquad [9]$$

$$\alpha_j^2 = (R_j^1 - R_j^3)/2 \qquad [10]$$

Referring now to FIG. 3, there is a schematic diagram of a phase correction circuit of the present invention that may be used with a remote mobile receiver. This phase correction circuit receives input signals R_j^2 and R_j^4 on leads 324 and 326 at symbol times *2T* and *4T*, respectively. Each input signal has a value determined by the transmitted pilot symbols as shown in equations [6] and [8], respectively. The phase correction circuit receives a complex conjugate of a channel estimate of a Rayleigh fading parameter α_j^{1*} corresponding to the first antenna on lead 302 and a channel estimate of another Rayleigh fading parameter α_j^2 corresponding to the second antenna on lead 306. Complex conjugates of the input signals are produced by circuits 308 and 330 at leads 310 and 322, respectively. These input signals and their complex conjugates are multiplied by Rayleigh fading parameter estimate signals and summed as indicated to produce path-specific first and second symbol estimates at respective output leads 318 and 322 as in equations [11] and [12].

$$R_j^2\alpha_j^{1*} + R_j^{4*}\alpha_j^2 = (|\alpha_j^1|^2 + |\alpha_j^2|^2)S_1 \quad [11]$$

$$-R_j^{2*}\alpha_j^2 + R_j^4\alpha_j^{1*} = (|\alpha_j^1|^2 + |\alpha_j^2|^2)S_2 \quad [12]$$

These path-specific symbol estimates are then applied to a rake combiner circuit 404 (FIG. 4) to sum individual path-specific symbol estimates, thereby providing net soft symbols or pilot symbol signals as in equations [13] and [14].

$$\tilde{S}_1 = \sum_{j=1}^{L} R_j^2\alpha_j^{1*} + R_j^{4*}\alpha_j^2 \quad [13]$$

$$\tilde{S}_2 = \sum_{j=1}^{L} -R_j^{2*}\alpha_j^2 + R_j^4\alpha_j^{1*} \quad [14]$$

These soft symbols or estimates provide a path diversity L and a transmit diversity 2. Thus, the total diversity of the STTD system is $2L$. This increased diversity is highly advantageous in providing a reduced bit error rate.

Referring now to FIG. 4, there is a simplified diagram of a mobile communication system that may use the phase correction circuit (FIG. 3) with closed-loop power control of the present invention. The mobile communication system includes an antenna 400 for transmitting and receiving external signals. The diplexer 402 controls the transmit and receive function of the antenna. Multiple fingers of rake combiner circuit 404 combine received signals from multiple paths. Symbols from the rake combiner circuit 404, including pilot symbol signals of equations [13] and [14], are applied to a bit error rate (BER) circuit 410 and to a Viterbi decoder 406. Decoded symbols from the Viterbi decoder are applied to a frame error rate (FER) circuit 408. Averaging circuit 412 produces one of a FER and BER. This selected error rate is compared to a corresponding target error rate from reference circuit 414 by comparator circuit 416. The compared result is applied to bias circuit 420 via circuit 418 for generating a signal-to-interference ratio (SIR) reference signal on lead 424.

Pilot symbols from the rake combiner 404 are applied to the SIR measurement circuit 432. These pilot symbols are obtained from a common pilot channel similar to a broadcast channel. The

SIR measurement circuit produces a received signal strength indicator (RSSI) estimate from an average of received pilot symbols. The SIR measurement circuit also produces an interference signal strength indicator (ISSI) estimate from an average of interference signals from base stations and other mobile systems over many time slots. The SIR measurement circuit produces an SIR estimate from a ratio of the RSSI signal to the ISSI signal. This SIR estimate is compared with a target SIR by circuit 426. This comparison result is applied to TPC command circuit 430 via circuit 428. The TPC command circuit 430 sets a TPC symbol control signal that is transmitted to a remote base station. This TPC symbol instructs the base station to either increase or decrease transmit power by preferably 1 dB for subsequent transmission.

Referring now to FIG. 5, there is a block diagram showing signal flow in a communication network of the present invention. The communication network includes a network control station 500 connected to each remote base station 502-506. The network control station transmits and receives frames of data in predetermined time slots via the base stations. The network control station performs many other functions including power control and communicating with other communication networks. The network control station initiates SSDT communication with the mobile unit 512 preferably during a soft handoff period such as when the mobile unit moves from one base station to another. This soft handoff period requires the mobile unit 512 to select one of base stations 502-506 with which to communicate. The mobile unit receives an active list from the network control station by which it may identify each base station. The mobile unit also receives information on transmit diversity for each respective base station. For example, the mobile unit determines that base station 502 employs STTD and that base stations 504 and 506 employ no diversity. The mobile unit calculates a SIR from received pilot symbols for each base station and selects one of the base stations as a primary base station. The mobile then transmits 510 the identity of this primary base station back to the network control station via a base station. The network control station then terminates transmission of data symbols to the mobile unit 512 in the next data frame from all except the selected base station. This greatly reduces interference at the mobile unit during soft handoff.

Turning now to FIG. 6, there is a flow diagram showing base station selection of the present invention. The mobile unit receives an active list from the network control station upon SSDT initialization. The mobile unit calculates a SIR for each base station on this active list from the received pilot symbols. The respective SIR signals for each base station are applied via leads 600-604 to selection circuit 620. Selection circuit 620 receives diversity signals corresponding to each base station on leads 606-610. These diversity signals indicate whether the respective base station employs transmit diversity. The selection circuit receives a reference signal η on lead 612. This reference signal together with SIR and diversity signals is used to select a primary base station as indicated in TABLE II.

BTSx	BTSy	Criteria	Selection
ND	ND	SIRx > SIRy	BTSx
		SIRy > SIRx	BTSy
STTD	STTD	SIRx > SIRy	BTSx
		SIRy > SIRx	BTSy
STTD	ND	SIRx > SIRy	BTSx
		SIRy > SIRx and SIRy - SIRx > η	BTSy
		else	BTSx
ND	STTD	SIRy > SIRx	BTSy
		SIRx > SIRy and SIRx - SIRy > η	BTSx
		else	BTSy

TABLE II

The entries of TABLE II show each condition for selecting between base stations BTSx and BTSy. These selection criteria, however, are generally applicable to any number of base stations. Transmit diversity is indicated as STTD but generally applies to any type of diversity. An absence of diversity is indicated as no diversity (ND). For the case where BTSx and BTSy have the same diversity, selection circuit 620 selects the base station with the greatest SIR. Alternatively, when one of the base stations employs transmit diversity, selection circuit 620 selects it as the primary base station if it has a greater SIR than the corresponding base station without diversity. If the base station without diversity has a greater SIR, however, then it is selected as the primary base station only if a difference between the diversity SIR and the non-diversity SIR exceeds the threshold signal η on

lead 612. This is highly advantageous in providing a selection bias in favor of transmit diversity. This is desirable due to the improved reception of orthogonal symbol transmission from the diversity antenna with STTD.

After the selection circuit 620 identifies a primary base station according to the selection criteria of TABLE II, mobile unit sends the identity of the primary base station back to the network control station 500 via a base station 630. For the case where base station 502 is selected, the network control station then terminates transmission of data symbols to the mobile unit 512 from base stations 504 and 506 for the next frame 640. All data symbols designated for mobile unit 512 are transmitted only by base station 502 in the next data frame. Pilot symbols, however, are transmitted for each base station. Thus, the mobile unit may repeat the base station selection process for subsequent data frames. This greatly reduces interference at the mobile unit during soft handoff. Moreover, the addition of transmit diversity in the selection criteria greatly improves communication within the system as will be discussed in detail.

Referring now to FIG. 8 there is a diagram showing simulation parameters for the simulation results of FIG. 9. The simulation is based on a Doppler rate for 3-kmph pedestrian travel with respect to the base station. The non-diversity simulation considers that three base stations transmit pilot symbols to the mobile unit. None of the simulated base stations employ transmit diversity. Thus, selection is based on maximum SIR. The diversity simulation considers that three base stations transmit pilot symbols to the mobile unit. All of the simulated base stations employ STTD. Thus, base station selection is again based on maximum SIR. Referring to FIG. 9, the STTD and SSDT dashed curve shows a 1.1 dB improvement over the SSDT solid curve for a 10^{-3} coded bit error rate (BER). Thus, communication is greatly improved by including STTD with SSDT in the communication system. Interference at the mobile unit as well as within the cell is greatly reduced. Moreover, improved soft handoff decisions are quickly made by the mobile unit in the absence of interference from other base stations.

Although the invention has been described in detail with reference to its preferred embodiment, it is to be understood that this description is by way of example only and is not to be construed in a limiting sense. For example, advantages of the present invention may be achieved by a digital signal processing circuit as will be appreciated by those of ordinary skill in the art having access to the instant specification. Furthermore, the advantages of alternative forms of transmit diversity combined with SSDT provide a corresponding improvement in communications.

It is understood that the inventive concept of the present invention may be embodied in a mobile communication system as well as circuits within the mobile communication system. It is to be further understood that numerous changes in the details of the embodiments of the invention will be apparent to persons of ordinary skill in the art having reference to this description. It is contemplated that such changes and additional embodiments are within the spirit and true scope of the invention as claimed below.